INFLUENCE OF STEMFLOW ON SOIL

V.N. MINA, Laboratory of Forest Science, USSR Academy of Sciences

An overwhelming majority of researchers consider atmospheric precipitation penetrating a forest canopy to be one of the intake aspects of a soil's water balance and the source of water for plants. Considerably less attention has been paid to the composition of rain waters and the amount of substances trapped by these waters as they penetrate the tree crowns. There is unusually little information in literature on the composition of stemflow. Some data can be found in the publications of Pozdnyakov [7, 8], Zonn, Karpachevskiy, Stefin [2], Protopopov [9], Fedchenko [11], Kaul and Billings [17], and Mina [5].

These studies have revealed great differences in the composition of stemflow, depending upon the amount of stemflow during one rain storm, duration of the dry period which

preceded the precipitation, the tree species, and the character of the bark surface. The composition of this stemflow often differs substantially from the composition of the throughfall.

The characteristics of the composition of stemflow for certain woody species and the systematic uptake of stemflow by soil about the trunk over the entire life span of a tree give us reason to assume that this stemflow has a definite influence on soil properties. This problem has not been treated in literature. In research devoted to studying the influence of individual trees on soil properties, the evaluation of changes observed was made on the basis of analyzing soils at varying distances from the tree trunk. In some cases [12, 1] the soil profiles were taken 0.5-1.0 m outward from the trunk, i. e., apparently outside the influence of stemflow, while in other cases [10, 18] profiles were taken 0.25-0.30 m from the trunk. The influence of stemflow on soil in these studies was not determined. Only in the work of Zinke [18] is there a reference to the effect that the amount of water flowing down the trunks and from the leaves may, besides the composition of the litter, have an influence on the change in a soil's properties depending upon its distance from the trunk (considered as the center from which the influence of the individual plant extends).

The authors of the foregoing investigations have consistently painted a picture of a change in a soil's properties as the result of the influence of individual trees of different species. It is pointed out that coniferous species have a greater influence and deciduous species (birch, basswood) a lesser effect. No regular changes associated with the distance from the tree were observed in the oak stand [10]. Maximum soil acidity and leaching were observed nearer the trunks.

This paper presents the results of a study of the influence of stemflow, primarily from pine, on certain soil properties and expresses quantitatively the changes produced and their stability. [1]

[1] Analytical work was performed by S.I. Klimova.

Investigations were mainly carried out in a mountain ash-hazelnut pine stand on a Sod-Weakly Podzolic loamy sand soil in the Moscow region. Some observations were made of spruce, birch, and pine at the Rybinsk Leskhoz of the Yaroslavl' Oblast.

A study of the composition of precipitation penetrating the forest canopy [5] has revealed that the acidity and concentration of the separate elements and soluble organic substances in stemflow from such species as spruce, pine, and basswood are considerably higher than in the throughfall (Table 1). The stemflow from birch and mountain ash with a smooth bark is characterized by a low acidity and a small amount of mineral and organic compounds.

The high acidity of stemflow from spruce and pine, when there is a large number of bases, indicates the acidic nature of a large part of the organic substances in these solutions.

The amount of stemflow from spruce, as a result of the peculiarities of crown structure and foliage density, is several times less than that from pine and birch. For example, 22 liters of water were collected in 4 summer months from one pine trunk, about 20 liters from birch, and only 5 liters from spruce (of large diameter).

It is an established fact that the different species of trees also differ in the amount of precipitation retained and in the character of the redistribution of throughfall and the precipitation entering the soil surface. Figure 1 shows the distribution of precipitation beneath spruce and pine crowns at varying distances from the trunk, based on data from two observations of each species. It is clear that precipitation beneath spruce is distributed eccentrically, increasing toward the edges of the crown but being more evenly distributed beneath pine. Retention of precipitation by the pine crown is greatest near the trunk and along its edges. Thus, a soil near a spruce trunk receives less throughfall than a soil near pine and receives hardly any additional water because of stemflow.

Stemflow from pine is heterogeneous in its composition both with respect to the amount of water received during one rain

Table 1 — Acidity and concentration of certain elements in precipitation

Forest type	Soil	Species	Range of pH	Total acidity in H^+	Oxidizability in O_2	Ca	Mg	K	Ammonium N
						mg/liter			
Oxalis-fern spruce	Coarse loam Sod Weakly-Podzolic	Spruce	5.0-6.0 / 2.7-3.4	0.02 / 2.64	80 / 520	4.0 / 163.0	1.2 / 12.0	6.2 / 51.0	1.1 / 11.0
Whortleberry spruce	Coarse loam Strongly Podzolic		4.6-5.4 / 2.6-3.5	0.14 / 2.70	160 / 580	6.6 / 167.0	2.1 / 10.0	8.0 / 46.0	1.0 / 13.0
Mixed-grass birch	Coarse loam Sod Weakly-Podzolic	Birch	4.7-5.7 / 3.7-5.0	0.04 / 0.43	90 / 70	3.9 / 3.0	0.8 / 1.0	2.4 / 1.0	0.9 / 1.0
Whortleberry birch	Coarse loam Strongly Podzolic		4.5-5.9 / 4.0-4.8	0.11 / 0.39	80 / 60	6.0 / 2.2	1.2 / 0.4	3.1 / 1.0	1.2 / 1.0
Whortleberry pine	Sandy Podzol	Pine	3.7-5.5 / 3.3-4.7	0.22 / 1.07	127 / 240	7.1 / 24.0	1.5 / 4.0	5.8 / 7.0	2.3 / 3.0
Mountain-ash hazelnut pinte	Loamy sand Sod Weakly-Podzolic		4.7-5.9 / 2.8-3.5	—	—	9.8 / 37.0	1.7 / 6.0	3.5 / 9.0	2.7 / 15.0
Same	Same	Mountain ash	5.3-5.9 / 4.5-4.9	—	—	8.5 / 10.0	2.3 / 2.0	4.6 / 4.0	1.8 / 3.0
"	"	Basswood	5.4-5.9 / 3.3-3.6	—	—	14.6 / 58.0	2.4 / 10.0	6.2 / 36.0	2.6 / 19.0

Note. Weighted average concentrations of elements are given: numerator — the throughfall; denominator — the stemflow.

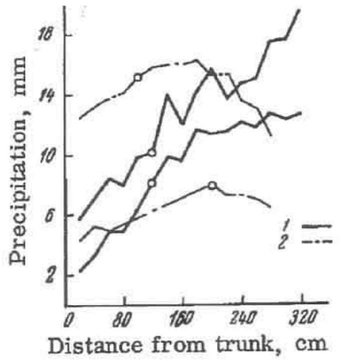

Fig. 1. Distribution of precipitation beneath crowns (two observations).

1) spruce; 2) pine (small circles indicate amount of precipitation in an open area).

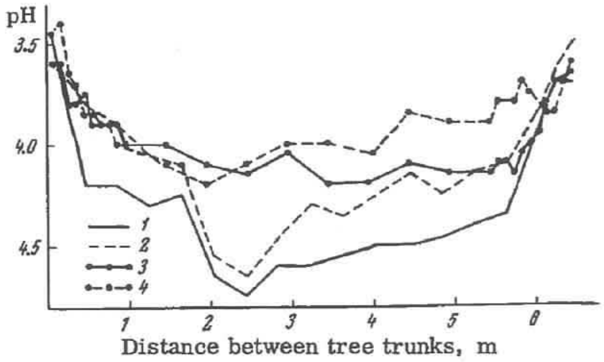

Fig. 2. Acidity of litter and a soil's humus horizon between pine trunks.

July 16, 1963: 1) in litter; 2) in soil (A_1 horizon); October 18, 1965: 3) in litter; 4) in soil (A_1 horizon).

storm and the individual characteristics of the tree: extent to which the trunk is free from dead twigs and the height to which the trunk is covered by knobby bark.

These details could not be clearly determined through direct observations of stemflow from growing trees, but a simple experiment — preparation of water extracts[2] from individual tree parts, which simulate stemflow, reveals definite differences. Extracts from live branches with bark have a pH of 5.0, extracts from dead twigs without any bark have a pH of 3.4; trunk sections with a smooth bark have a pH of 5.3 and sections of the lower part of a trunk with knobby bark a pH of 3.25.

The pH of extracts from the bark of two pines, the knobby bark of one of which was 11 m high and that of the other 3 m high showed that the pH value in the first pine at a height of 11 m was 3.4, at a height of 5 and 1 m — 2.8, while in the second pine the pH was 3.4 at a height of 3 m and 3.1 at a height of 1 m.

A mound of litter is generally formed about the pine trunk directly at its base. The litter here is thicker than further out from the trunk and its formation is dependent, in relatively large measure, to fallen bark. Since the decomposition products, which are leached from this litter, have a clearly expressed acid character, the stemflow filtering through it is even more acidified.

The amount and composition of stemflow must obviously be considered as the main cause of the changes observed in soils near tree trunks. This conclusion is strengthened by the following data. In July 1963, the pH (of water suspension) was measured between two pines in a 40-year-old pine stand growing on Sod Weakly-Podzolic soils, in samples consisting of litter and the soil's humus horizon, taken in a straight line with spacings of not more than 30 cm between individual samples. Next, a 30-cm-wide ditch was dug along the same straight line. A 5-cm-thick litter and humus horizon were removed separately, and carefully mixed, after which they were restored to their former place. A little more than 2 years later, in October 1965, the acidity in the litter and soil samples taken from the ditch was again determined.

From the original 1963 data (Fig. 2), we see a gradual increase in litter and soil acidity as the distance from the trunks decreases. Especially clear is the change in acidity in areas extending 40-50 cm outward from the trunk. The pH values in 1965 were almost the same as the original values. Slight differences in these values are explained by dissimilar meteorological conditions: the dry year 1963 is characterized by a lower acidity and the rainy year of 1965 has a higher acidity.

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[2] Extracts were prepared in distilled water in the amount of 1 ml of water for 10 cm^2 of surface; shaking lasted 15 min. The butt-ends were sealed by a waterproof film.

Table 2 — Acidity (water pH) of litter and soil at varying distances from a tree trunk

Tree (type)	Horizon	Distance from trunk, cm									
		10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100
Moscow Oblast											
Mountain-ash hazelnut pine. A 120-year-old pine.	A_0	3.5	3.5	3.6	4.0	4.2	4.6	—	4.6	—	5.0
	A_1	3.5	3.8	3.8	3.9	4.0	4.2	—	4.1	—	4.5
	A_1A_2	3.7	3.8	4.0	4.1	4.1	4.3	—	4.3	—	4.4
Pine stump (pine cut 60-70 years ago)	A_0	4.5	4.8	4.9	5.1	5.2	5.2	5.3	5.1	5.2	5.3
	A_1	3.8	3.9	4.2	4.3	4.4	4.4	4.4	4.5	4.4	4.3
	A_1A_2	4.0	4.0	4.2	4.2	4.3	4.2	4.3	4.3	4.3	4.2
70-year-old birch	A_0	4.2	4.3	4.6	5.0	5.2	5.0	—	5.2	—	5.5
	A_1	3.9	3.9	4.2	4.6	4.5	4.5	—	4.5	—	4.6
	A_1A_2	4.0	4.0	4.2	4.4	4.4	4.5	—	4.4	—	4.5
Basswood	A_0	4.5	4.5	5.1	5.4	5.2	5.2	5.3	5.2	5.2	5.4
	A_1	3.7	4.0	4.2	4.2	4.0	4.1	4.3	4.3	4.1	4.4
Oak	A_0	4.0	4.0	4.3	4.1	5.1	3.9	4.5	4.4	4.1	4.6
	A_1	3.7	3.4	3.4	3.4	3.5	3.5	3.6	3.6	3.5	3.6
Yaroslavl' Oblast											
Spruce (type—Oxalis-fern spruce)	A_0	4.7	4.8	4.7	4.8	4.7	4.6	4.9	5.3	—	—
	A_1	4.9	4.7	4.9	5.0	4.7	4.7	4.7	4.8	—	—
Birch (type—mixed-grass birch)	A_0	6.1	5.4	5.4	5.5	5.3	5.1	4.9	5.0	—	—
	A_1	4.3	4.2	3.9	4.0	3.8	3.7	3.6	3.6	—	—
Spruce (type-whortleberry spruce)	A_0	4.4	4.5	4.1	4.0	4.0	4.0	3.8	3.7	3.6	3.5
	A_0	4.0	4.0	3.9	3.9	3.8	3.8	3.7	3.6	3.4	3.4
	A_1A_2	3.6	3.5	3.5	3.5	3.4	3.4	3.3	3.3	3.25	3.2
50-year-old pine (type—whortleberry pine)	A_0	3.7	4.0	4.2	4.5	4.6	4.4	4.3	4.3	—	—
	A_1A_2	3.8	4.0	3.9	3.9	4.2	4.2	4.2	4.2	—	—

No accumulation of fallen bark was observed in the litter about the trunk from the time the experiment began until the time of calculation. Consequently, we may assume that the acidification of the litter and soil near the pine trunks was mainly due to acid waters flowing down from the tree trunks.

Data on a determination of the total exchangeable bases also revealed similar results. The litter and soil of the humus horizon in areas directly contiguous to the trunks were the most leached 2 years after the start of the experiment. The amount of exchangeable bases increased rapidly outward from the trunk, reaching an average value typical of the trench plot located between trunks 50-60 cm away.

A more detailed study of the influence of stemflow on soil was made with individual trees of different species.

A horizontal change in the acidity of the litter and soil of the humus horizon was observed in samples taken at varying distances from the trunk base.

The influence of stemflow was studied in detail by comparing data on different types of acidity, mobile aluminum (after Sokolov), and iron (after Tamm) in individual soil samples removed by an auger directly at the trunk within the zone of influence of stemflow and between trees (as control samples).

Stemflow from pine has the greatest effect radially on the difference in acidity in litter and soil (Table 2). Acidification extends 40-50 cm outward from the trunk. Similar pH changes are observed in Sod Weakly Podzolic loamy sand soil near birch and basswood trunks, but the values are leveled nearer the trunk at a distance of 30 cm and the differences in pH values here

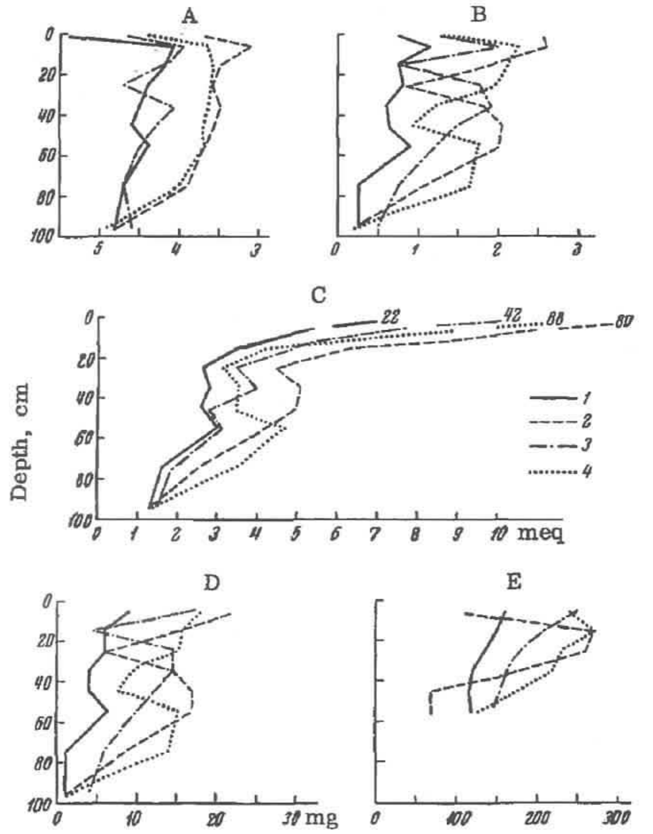

Fig. 3. Chemical properties of loamy sand Sod Weakly Podzolic soils.

A) water pH; B) exchangeable acidity; C) hydrolytic acidity; D) mobile aluminum content; E) content of mobile iron (after Tamm); 1) between trunks; 2) near a pine trunk; 3) near birch; 4) near a pine stump.

are less. No natural differences in litter and soil acidity were observed near oak. In soils near spruce trunks, in the subzone of the southern taiga, there are either no differences at all (in Weakly Podzolic coarse loam soil) or the changes are in an opposite direction — decreasing acidity outward from the trunk (in Strongly Podzolic coarse loam soil). Similar to this is the change in the pH near birch trunks in a birch stand, derived from Oxalis-fern spruce on Weakly Podzolic coarse loam soil.

The reasons for an increase in litter and soil acidity near pine trunks have been discussed previously. There is no acidification of soil near spruce trunks, despite the high acidity of stemflow. This is the result of a very low amount of stemflow. In addition, a considerable abount of precipitation is retained on the branches as a result of the peculiarities of the crown structure of spruce, and the soil near the trunks and beneath the middle part of the crown not only receives no additional water but is significantly drier here than in areas of crown periphery projection or between trees.

Given such a character of distribution of precipitation, the litter and soil acidity at varying distances from spruce trunks, as noted above, is either homogeneous or reflects an eccentric distribution of precipitation. In our studies the acidification of soil beneath the periphery of a spruce crown in a whortleberry spruce stand is obviously due to the higher acidity of throughfall, as compared with the Oxalis-spruce (see Table 1).

The permanency of the increase in soil acidity under the influence of stemflow was determined by analyzing samples taken near an old decomposed pine stump. It was presumed that this pine had been cut 60-70 years ago. The data obtained showed that the changes in acidity near the stump are similar to those near a live pine, but the increase in acidity is somewhat less toward the stump (Table 2).

The changes observed in the acidity of litter and the upper soil horizons have raised the question of the depth to which the influence of stemflow on soil extends.

What follows does not pretend to be an exhaustive treatment of this problem. A comparative study of different types of acidity and of such associated indices as content of mobile aluminum and more stably bound iron passing into an oxalate extract has been made in a soil profile located directly near pine and birch trunks, a pine stump, and in spacings between trees. The data in Fig. 3 consistently and quite clearly reflect the results of the influence of stemflow on the properties of Sod Weakly-Podzolic loamy sand soils studied. Changes in properties are observed to a depth of 1 m, and become imperceptible further down.

The greatest changes are observed in soil under pine. These changes are expressed in an increase in all types of acidity and an increase in the content of mobile aluminum and iron. Similar changes take place in soil under birch, but these changes are considerably less pronounced. Roughly the same pattern can be seen near the pine stump as under a growing pine, but the absence of stemflow for 60-70 years has brought about a decrease in the hydrolytic acidity of the litter and upper part of the soil out to a distance of 50-60 cm.

The increase in aluminum and iron mobility caused by stemflow was more permanent. The content of these elements in soil near the stump is similar to that under pine.

The only exception is the relatively low content of iron in the litter under pine. This can only be explained by the leaching of iron into the soil as the result of additional stemflow interacting primarily with the litter located directly near the trunk.

We have repeatedly made similar observations. The direction of the changes produced in the soil by acid stemflow enriched with organic compounds was similar to that explained previously; only the extent of these changes varied.

A sharp increase in iron and aluminum mobility in soil within the zone of stemflow influence is obviously due not only to the high acidity of stemflow but also to a high content of tannides, which form compounds of the polyphenol type during hydrolysis under the influence of enzymes. Studies by Bloomfield [13, 14, 15], Coulson [16], and Kaurichev [3, 4] have shown that polyphenols, leached by rain from live foliage (coniferous needles), leaf-fall and, to a lesser extent, from forest litter, form with the soil's iron stable, readily mobile complexes capable of migrating in the soil layer.

The presence of tannides in the bark of many woody species, including spruce and pine bark, was established long ago. According to Pavlov's data [6], the tannide content in pine bark ranges from 4 to 7% and its content in spruce bark from 7 to 12%. The tannide content is lower in the surface layers of bark, but, because of solubility in water, especially during the warm period of the year, the bark tannides doubtlessly enrich the composition of stemflow.

It could be assumed that the increase in the mobile aluminum content in soil under pine will be reflected in the distribution of active roots in the soil. However, calculation of the bulk of roots < 0.6 mm in diameter, within the zone of pine stemflow and beyond, has revealed no significant differences. Evidently, the toxicity limit of aluminum for pine roots is above the observed concentration (up to 20 mg per 100 g of soil).

CONCLUSION

Studies have established that stemflow has a definite influence on soil. Active, exchangeable, and hydrolytic acidity and the content of mobile aluminum and iron passing into an oxalate extract of soil increase depending upon the amount and composition of stemflow and, above all, upon its acidity in the soil.

The changes in soil properties are permanent. After stemflow ceases, the changes which had taken place earlier in the soil are preserved for many scores of years and some of these changes are probably irreversible.

The influence of stemflow on soil is localized about the trunk and extends radially 30-50 cm outward from the trunk and to a depth of 1 m (in loamy sand soils).

Stemflow from pine (of the species examined) has the greatest effect on soil. The direction and quantitative expression of the changes observed in soil under pine make it possible to view them as a local manifestation of an active podzol-forming process.

The spatial distribution of this phenomenon can be determined from the following example. In mature pine stands, the area of soil subjected to the influence of stemflow is 4-5% of the total area.

With a change in forest generations, trees usually grow again at different locations. The areas, earlier subjected to the influence of stemflow with stably altered soil properties, will develop a spatial heterogeneous soil cover.

Based on data presented in this paper, we can determine the quite rapid rate of development of acid stemflow effect on comparatively low buffer capacity of loamy sand soils. In any case, this rate is many times higher than the rate of restoring the original soil properties. This restoration takes place after stemflow, under the influence of other factors, which determine the direction of the soil-forming process and the formation of forest soils beyond the sphere of influence of stemflow.

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